

Whispering gallery resonators dispersion as internal temperature reference

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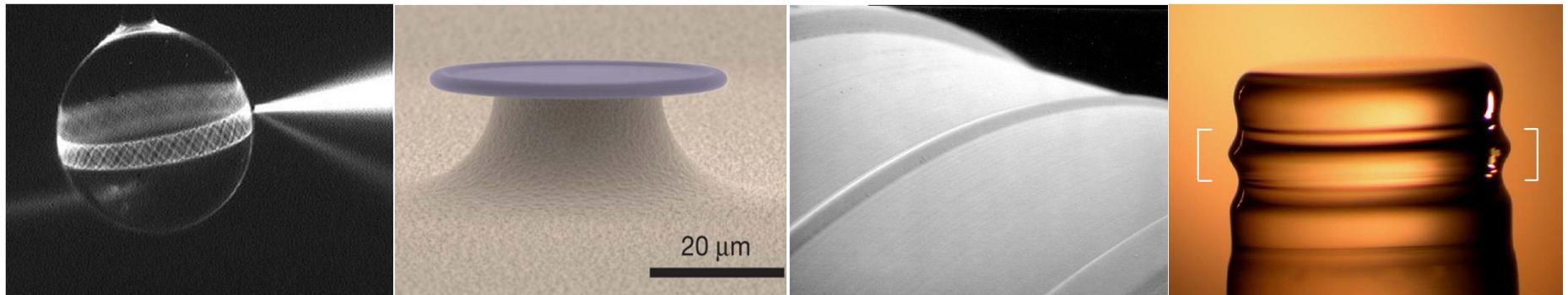


Caltech's Kavli Nanoscience Institute (KNI) and JPL's Microdevices Lab (MDL) seminar
April 2 2012

Whispering Gallery Mode resonators



St. Paul's cathedral, London [C.V. Raman and G.A. Sutherland, *Nature*, 1921].



A. Savchenkov *et al.*,
PRA, 2007.

P. Del'Haye *et al.*,
Nature, 2007.

A. Savchenkov *et al.*,
Opt. Lett., 2006.

I. Grudinin *et al.*, *Phys.
Rev. Lett.*, 2009.

WGMs in spherical geometry

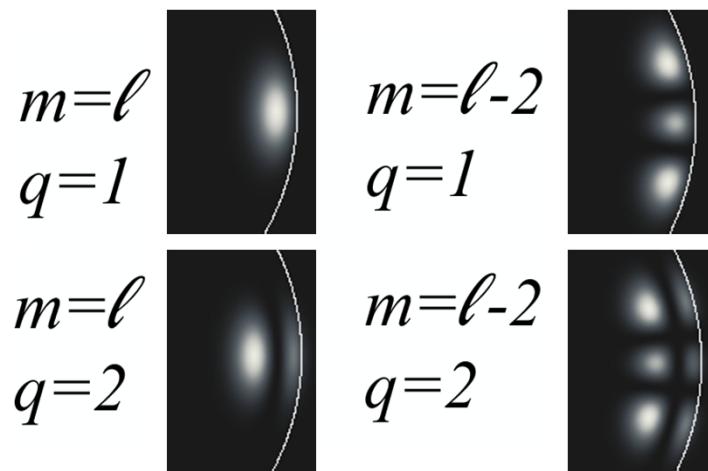
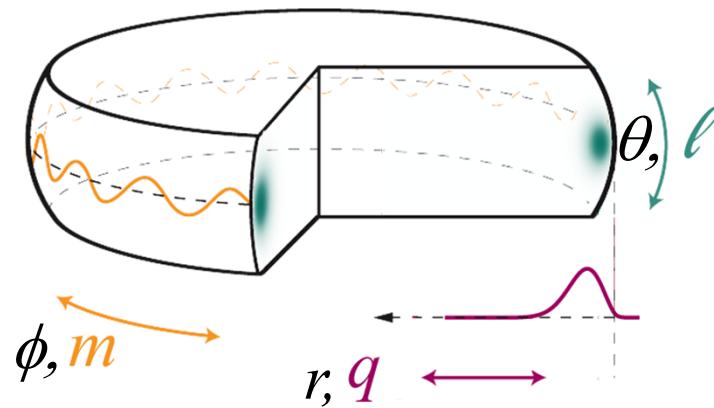


$$\Psi(r, \theta, \varphi) \approx P_L^m(\cos \theta) \frac{J_{L+1/2}(k_{L,q} r)}{r} e^{im\phi}$$

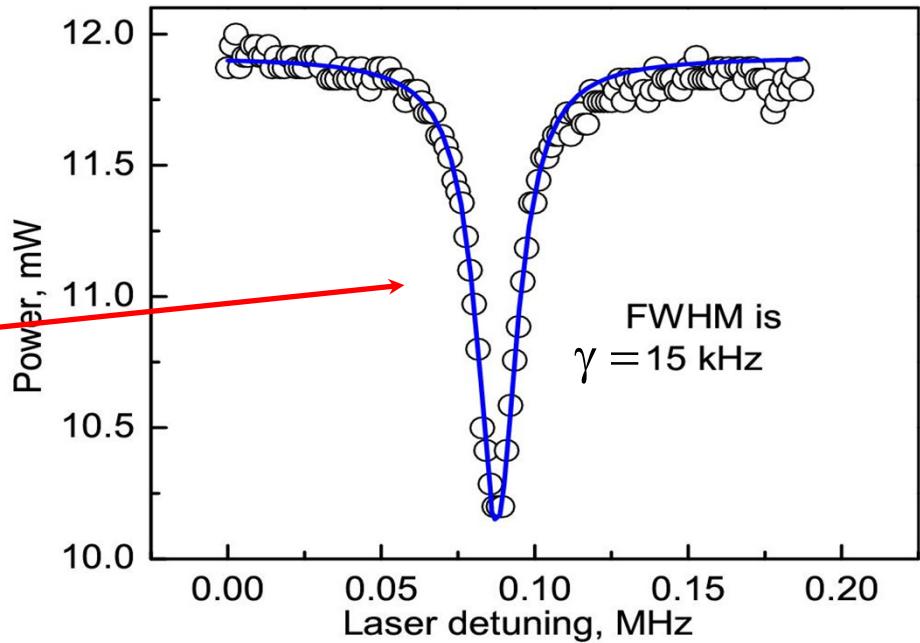
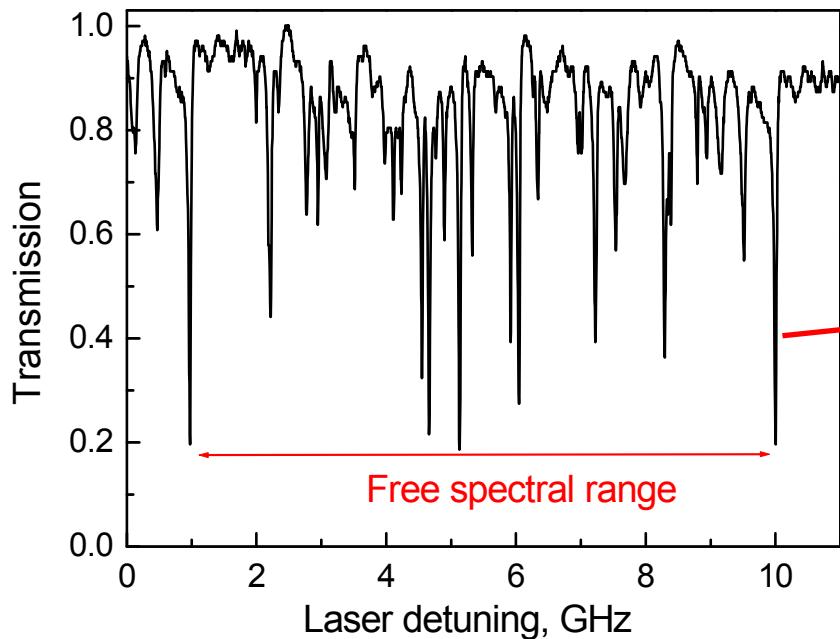
where

$$k_{Lq} = \omega \frac{n}{c} = \frac{L}{R} [1 + \alpha_q (2L^2)^{-1/3} + O(L^{-1})]$$

and α_q is the q -th root of the Airy function



Typical WGM spectrum



$$Q = \omega/\gamma > 2 \times 10^{10} \quad \text{Fluorite}$$
$$> 4 \times 10^8 \quad \text{LiNbO}_3$$

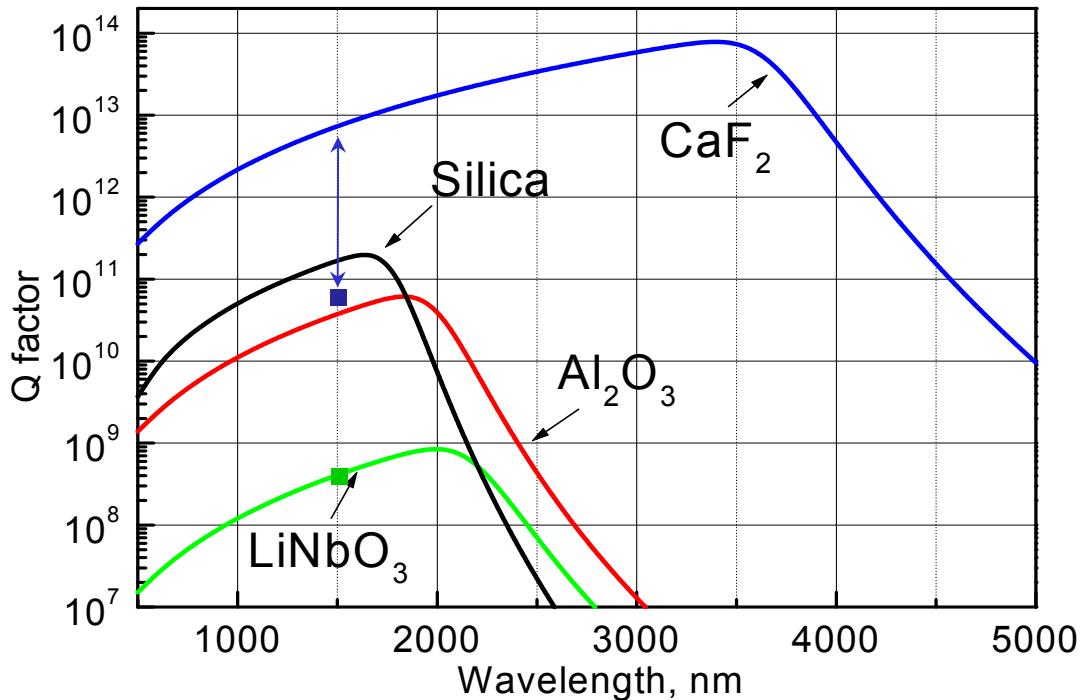
$$F = \Omega_{\text{FSR}}/\gamma \sim 6 \times 10^5$$

Ultimate Q

For crystalline resonators, linewidth is ultimately determined by the material absorption α :

$$2\gamma^{-1} = n(\alpha c)^{-1}$$

$$\Rightarrow Q = \frac{2\pi n}{\alpha \lambda}$$



$$\text{For } \alpha \simeq \alpha_{UV} e^{\lambda_{UV}/\lambda} + \alpha_R \lambda^{-4} + \alpha_{IR} e^{-\lambda_{IR}/\lambda}$$

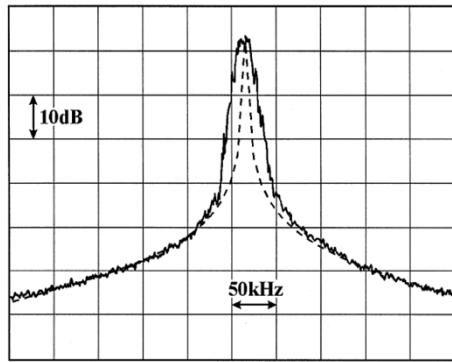
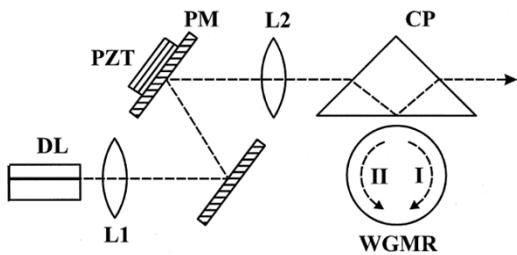
E.D.Palik, "Handbook on optical constants of solids", Academic, NY, 1998

WGM resonators applications

- Linear optics and telecom applications: optical filters, electro-optical modulators etc.
- Nonlinear optics applications: frequency doubling, low threshold OPOs etc.
- “Zeno-based” optical switch
- Cavity QED
- Optical material studies: photo refractivity etc.
- Quantum optics: squeezed and two-photon light
- Sensors (will discuss below)

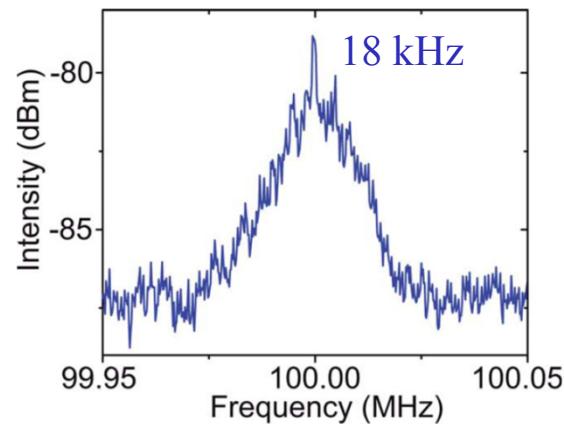
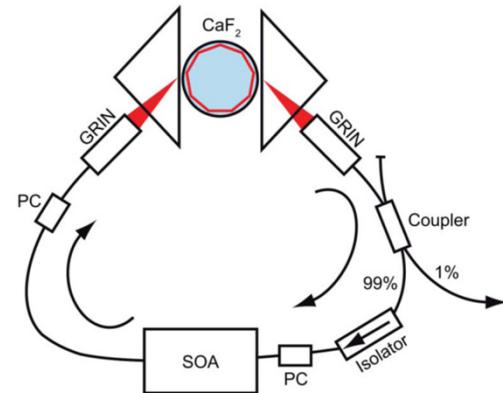
Laser frequency references

Injection locking



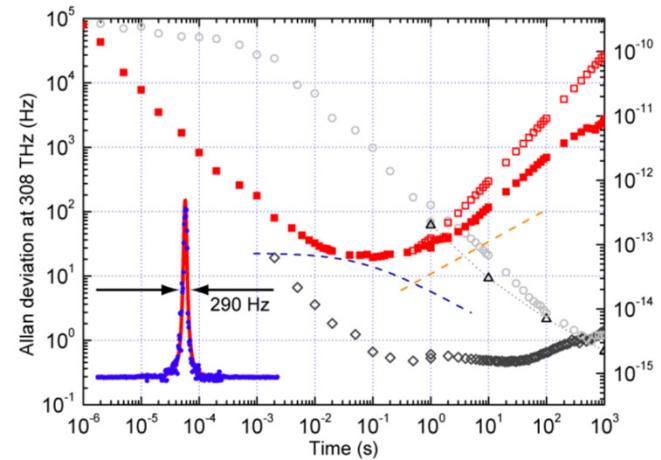
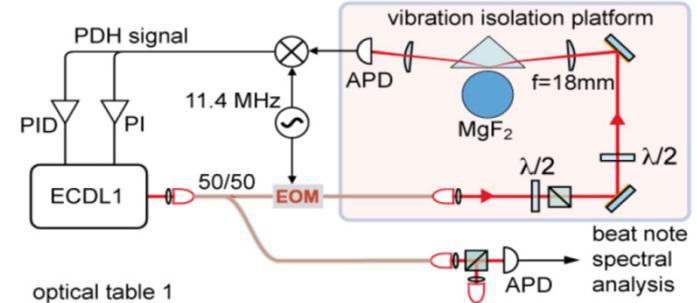
V.V. Vassiliev et al., Opt. Comm., 158, 305 (1998); W. Liang et al., Opt. Lett. 35, 2822 (2010)

Loop filter



A.B. Spenger et al., Opt. Lett., 35, 2870 (2010)

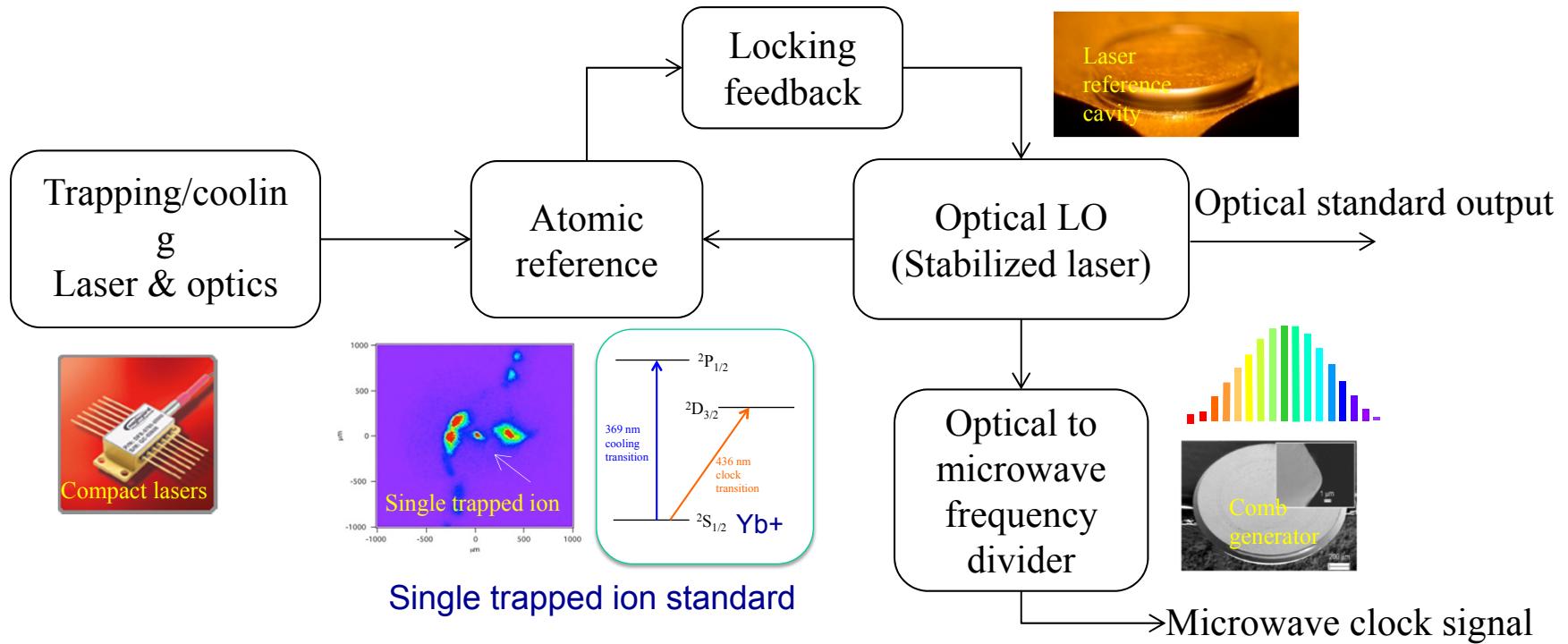
PDH lock



J.Alnis et al., arXiv:1102.4227v1 (2011)

Towards an ultra-compact optical clock

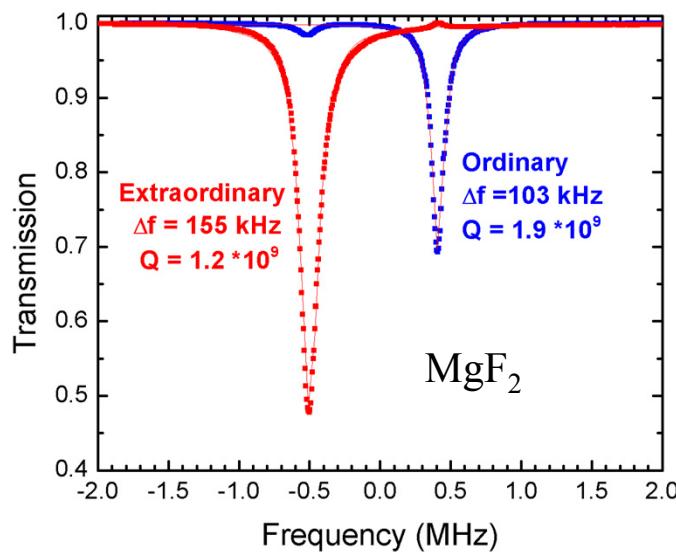
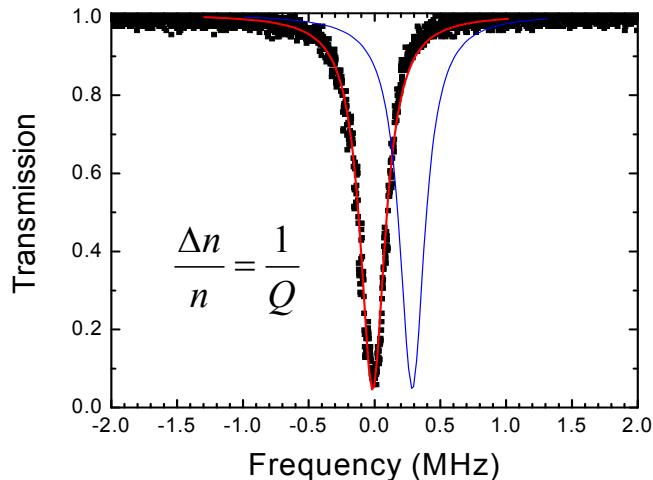
Can one envision to package everything into liter-sized device,
 $< 10 \text{ kg}$, $< 20 \text{ W}$, and $> \times 10$ improvement over microwave clocks of similar size?



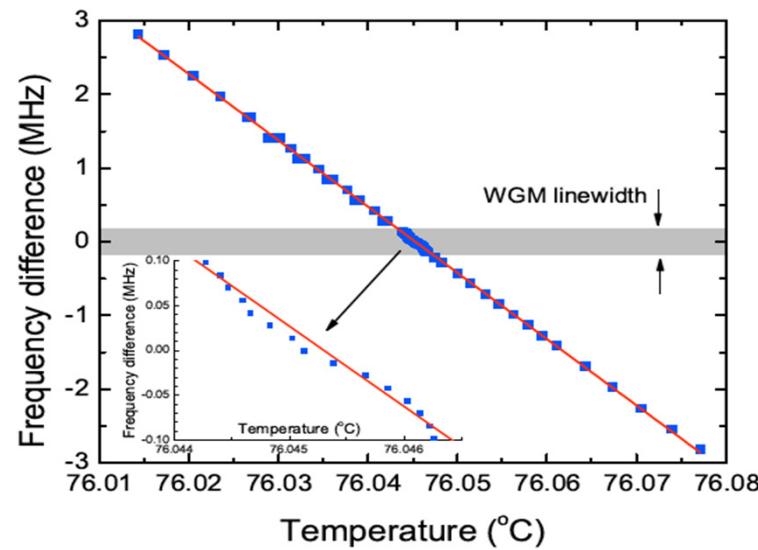
To realize the ultra-compact optical clocks

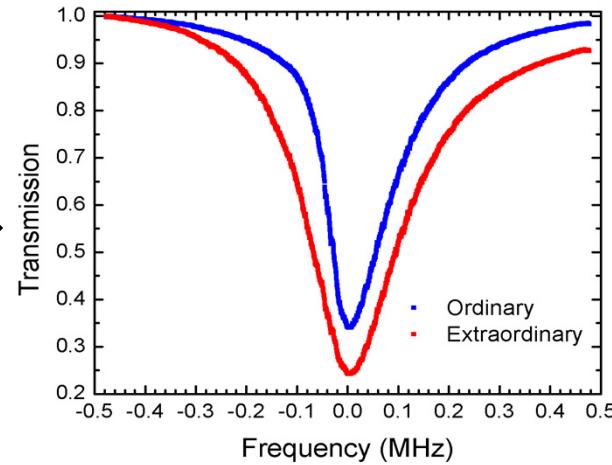
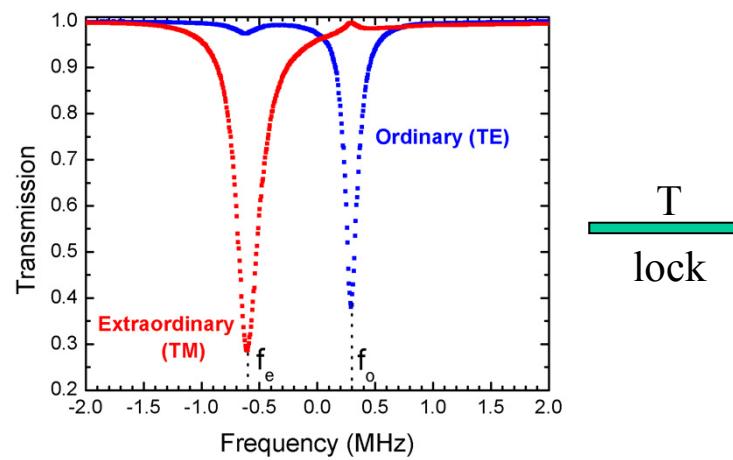
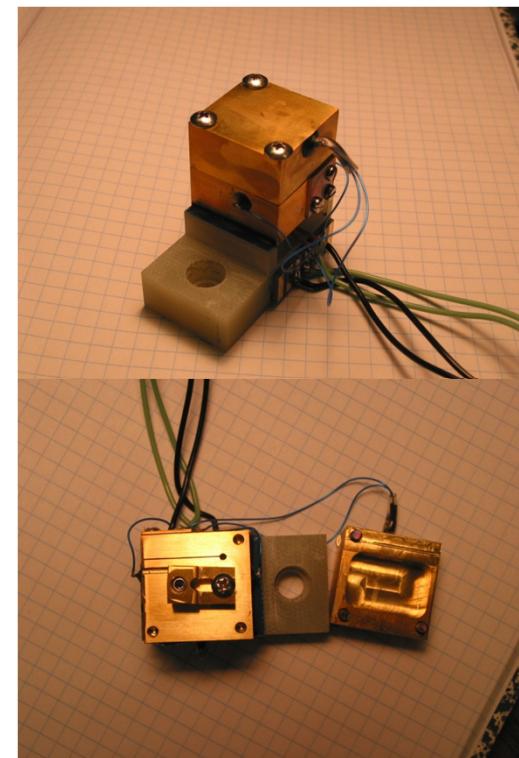
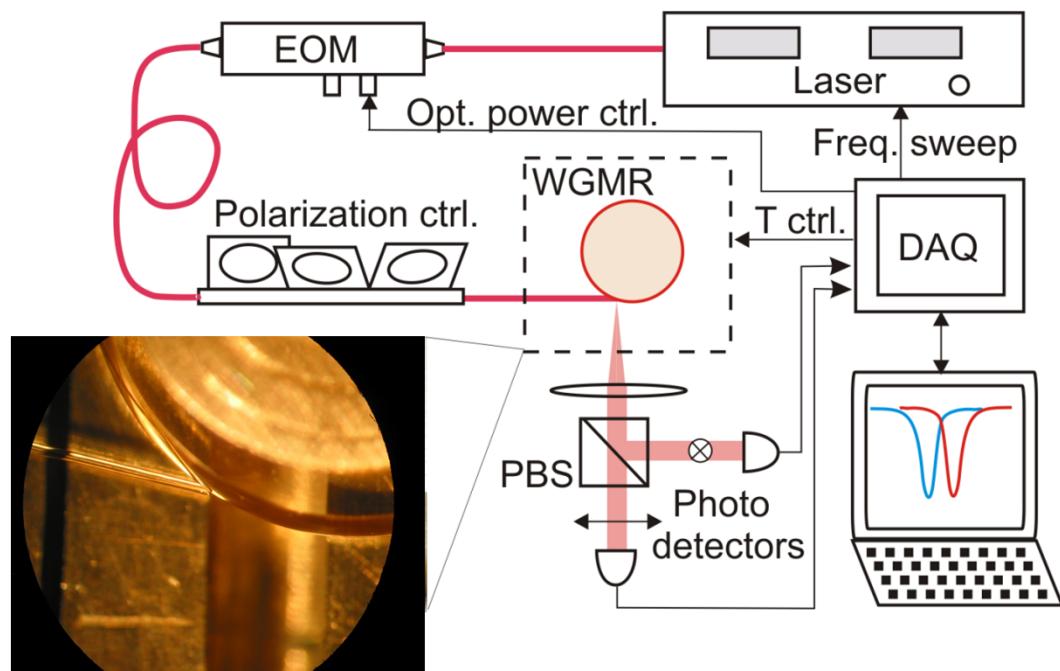
- Miniature physics packages
- Whispering gallery mode (WGM) resonator based narrow line lasers
- WGM resonator stabilized optical local oscillator
- WGM resonator comb generation

References... or sensors!

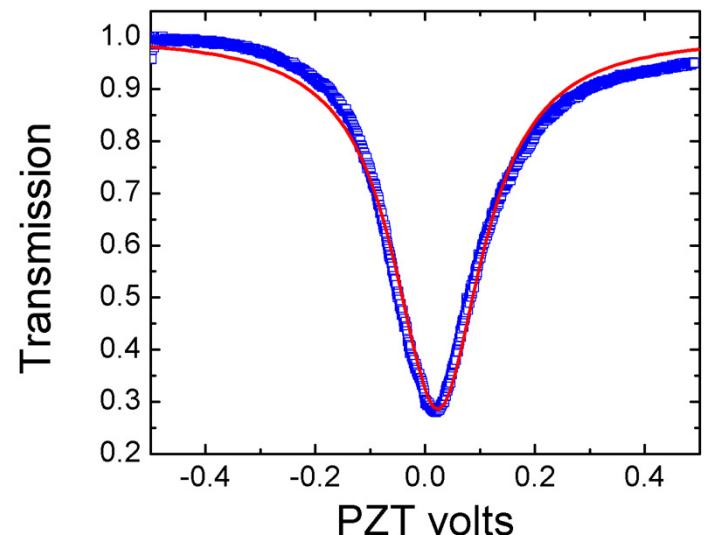


- Temperature ✓
 - Pressure (optomechanics!)
 - Electric field (in electro-optical crystals)
 - Bio- and Chemical detection
- [L.He et al., *Nature Nanotechnology* 6, 428 (2011)]
- Photorefractivity (in ferroelectrics), crystal ageing, etc.
 - Nonlinear optical phenomena (SPM, XPM)
 - Rotation (gyro?)

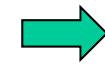
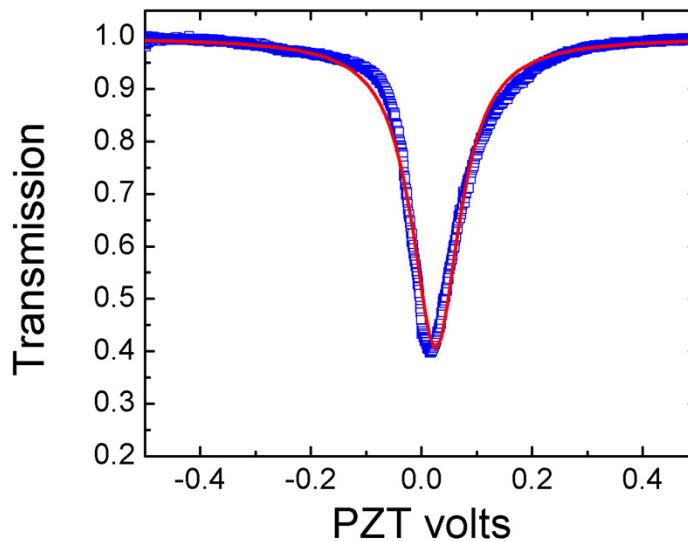




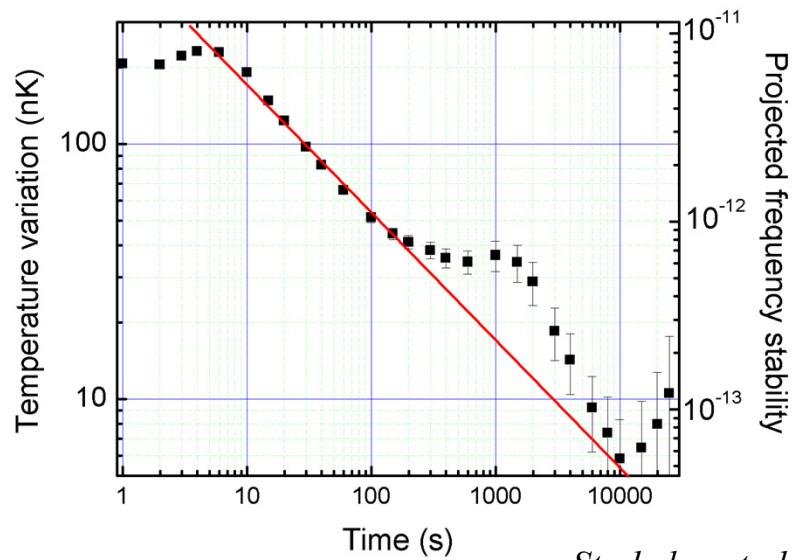
Extraordinary $\sigma_e(V_0) = 0.255$ mV



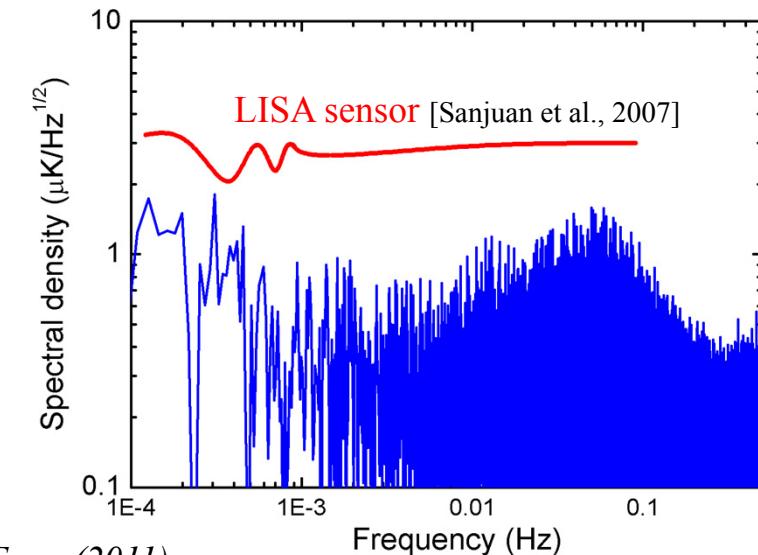
Ordinary $\sigma_o(V_0) = 0.166$ mV



Relative RMS = 4.78 μK per 10 ms

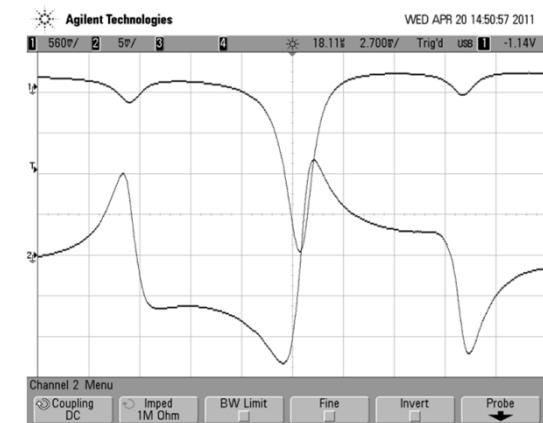
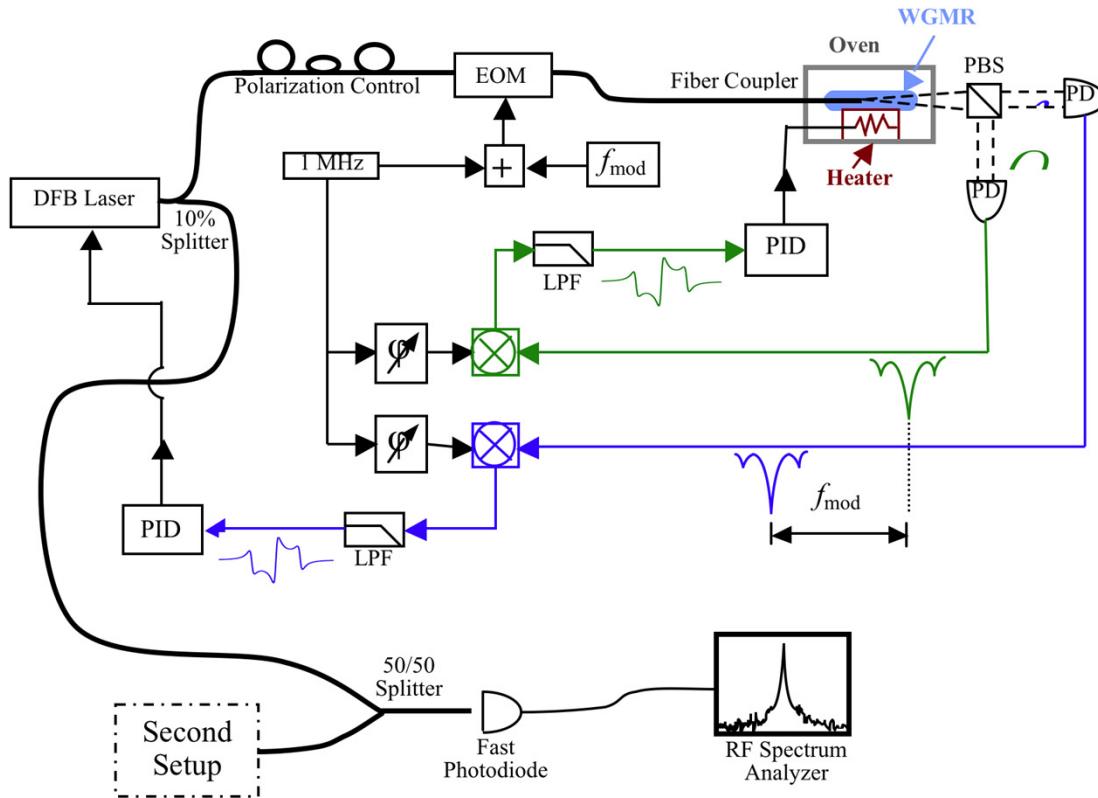


Strelakov et al., Opt. Expr. (2011)



What's next

PDH locking instead of laser tracking



Summary

“Optical whispering gallery resonators and their applications”

Applications in linear optics:

- Narrow-band filters for optoelectronics and laser stabilization
- Group-dispersion elements, optical delay lines
- High-index Bessel beams sources

Applications using electro-optical effect and second-order nonlinearities:

- Efficient electro-optical modulators
- Room-temperature THz sensors and sources
- Efficient frequency-doublers, sum and difference sources
- Narrow-band, low-threshold OPOs
- All-optical switches and modulators

Applications using Kerr nonlinearities:

- High-Q centimeter wave source
- Optical combs

Sensor applications:

- Temperature
- Pressure (optomechanics)
- Chemistry, biology
- Material science
- Gyro

We have a novel and powerful optical technology at hand!